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Economic Commission for Europe

EVALUATION OF EXISTING HYDRAULIC RESOURCES AND REQUIREMENTS

By The Energy Division
of the Economic Commission for Europe

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EVALUATION OF EXISTING HYDRAULIC RESOURCES AND REQUIREMENTS

(Report of the Energy Division of the Economic Commission for Europe to the United Nations Conference on the Application of Science and Technology for the Benefit of the less-developed Areas)

I. Introduction

1. Adequate reserves of water are essential to civilized living. Although water supply, like electric power, is a basic public utility, even a rough evaluation of national resources and needs in this field is a task of the greatest difficulty in most countries. In part this is due to inherent difficulties of survey and measurement; in part to the fact that systematic observing and recording on a national scale are too often a recent development; and, finally, because of the frequent division of responsibilities for measurement or for water supply itself between several quite distinct authorities or even a multiplicity of local undertakings.

2. In a short paper it is possible only to concentrate on essentials. The analysis which follows is concerned with steps which may be taken and methodological principles involved in gaining a first rough but comprehensive sketch of the hydraulic resources of a country - including a broad idea of its potential water economy and of the possible evolution of requirements - where stream-flow records exist for a portion of the area only and are inadequate in duration; where knowledge of the present scale of different water requirements is meagre; and where their likely rates of increase are largely unknown. The purpose of such a preliminary sketch is thus to arrive,in advance of adequate data, at the broad geographical distribution of hydraulic resources; the location of hydro power potential; and the order of magnitude of needs for the various uses and their possible development - the whole providing at best a rough idea of the relationship between resources and requirements and a pattern for the planning of power supply and location of industry. There are thus two sorts of inquiry to envisage - a physical appraisal and an economic inventory.

II. The Physical Assessment

3. This ought to comprise as a minimum an assessment of:

- estimated mean annual surface runoff (m^3, m^3/s and $l/s/km^2$) for a breakdown of catchment areas extending throughout the country;
- average monthly values for the above or for principal catchment basins;
- year-to-year fluctuations in a selection of monthly records, i.e. the range and frequency of departure from average values;
- the range of inter-basin diversity in departures from mean flow conditions at a given time;
- the mean energy potential in each basin as defined by its stream flow and mean elevation.

4. For each of the above catchment basins it is thus necessary to establish an average elevation above mean sea level and the elevation of the point at which runoff is defined. The best available topographical maps at medium scales are therefore required.

(a) Stream-flow and runoff assessment

5. Where flow data are inadequate catchment basins may conveniently be classified in three groups (categories 1 - 3 respectively), i.e. those for which river stage records allow stream flow data to be determined over, say, ten or more consecutive years; those for which this can be done for between, say, four and nine years or for which incomplete series can be supplemented by comparison with other records in the same area; and those for which stage records cannot yet be converted or for which they do not exist.

6. To deal with category 3 and possibly part of category 2 it is necessary to have access to the most detailed available map showing at least mean annual precipitation by isohyets and also mean monthly precipitation records for as wide a range of gauging points as possible. A geological map or equivalent information is also required.

7. The object of the analysis of these data is to compute mean runoff data (m^3, m^3/s and $l/s/km^2$) where it is lacking from a comparative study of all basins where mean precipitation and mean runoff depth in mm can be compared, the object being to ascertain the distribution and characteristics of the runoff deficit and the pattern of distribution of precipitation, evapo-transpiration and seepage for the region concerned from careful comparison of salient patterns and relationships.

8. It is unnecessary to describe such an analysis in detail here. References (1), (2) and (3) give some information on the application of such indirect and approximate methods to determine a preliminary view of the distribution of mean annual runoff and power potential throughout Turkey (for 92 catchment areas) and Greece (for 68 catchment areas). All basic data available at the time were brought together and analyzed for the purpose. From the results of such an analysis a comprehensive though very preliminary idea may be gained of the surface runoff and (by addition of data for separate catchments within a basin) the main stream-flow distribution. In the case of Turkey for example, only 25.5 per cent of the total area was covered by category 1 data at the time of the study. Where karst conditions exist (as in the above cases) a good deal of light may be thrown on the nature of the underground outflow by such comparative studies.

(b) Mean seasonal flow regime and its range of variation

9. The above method depends on the fact that, with the exception of gauging at high elevations, precipitation records and maps are usually more abundant and extensive than those for stream flow. To supplement monthly data from flow records by comparative study, aided by precipitation data, so as to obtain an approximate idea of the seasonal flow distribution in different regions is often possible and has been described in standard texts (4). It is desirable that consecutive series over a reasonable period (10 or more years) be available for at least some typical seasonal regimes in well-distributed basins so as to allow a range of modular coefficients about the mean as 100 to be established and curves drawn of the annual distribution of runoff throughout the year. A good deal of useful information can also be deduced from duration curves plotted as shown in Figure Ia. If such curves can be produced giving flow frequency throughout one mean year the duration and the volume of flow below the mean annual value and the level of the median yearly flow can be compared for different streams.

10. One practical purpose of this type of information is to throw light on the needs for regulation by reservoir storage. A useful step towards an understanding of this question can be obtained by calculating from monthly data, where these exist, indices of average within-year irregularity (C_r coefficients). This coefficient is defined as the average ratio (calculated at least over a few years) between the reservoir capacity needed to equalize the annual flow and the volume of annual flow. Its value, which commonly varies between around 0.05 and 0.35, can be mapped by isopleths and is then very instructive (5). It may well be used in conjunction with a map, obtained by interpolating isopleths between individual values for the different catchments, of mean annual specific runoff in $l/s/km^2$.

11. Reference has been made above to the important question of determining the frequency of occurrence of different rates of flow for corresponding periods over a given number of years. This is ultimately the basis from which the probability of occurrence of dry, normal or wet periods is assessed. Wherever observations exist over a period of the order of 20 years it is possible to compare different flow records by plotting series of values (for individual months on separate graphs) on logarithmic and probability scales of the type shown in Figure Ib (the example refers to two sets of six-monthly modular coefficients). To the extent that the series follows a normal distribution (in the statistical sense) it will approximate to a straight line. Such a diagram resembles a duration curve but allows the probability of different levels of occurrence of stream flow to be visualized and compared for different basins.

(c) Range of inter-basin diversity in departures from mean seasonal flow at a given time

12. This question is of importance if the region concerned is sufficiently large and topographically diversified for the timing of year-to-year fluctuations in precipitation to differ substantially in different parts of the area. Figure II shows the pattern of diversity in stream flow in Europe during two successive half-yearly periods, expressed by modular coefficients relative to the twenty-year averages for the summer and winter half-years as 100. Any such diversity which may exist is of practical importance from various points of view - for example, in allowing output from interconnected hydro power plants to complement one another and improve overall security of supplies of electric energy. It is evident, however, that the frequency of occurrence of departures from normal conditions should be known.

13. The Committee on Electric Power of the Economic Commission for Europe, through its Group of Experts for the Study of Hydro-electric Resources in Europe and their Utilization, is occupied with this question. It already issues a regular Half-Yearly Bulletin on Conditions of Hydraulicity in Europe and in which monthly, six-monthly and yearly data, and maps similar to those in Figure II, show flow conditions relative to corresponding 20-year averages. It has also adopted definitions of very wet, wet, normal, dry and very dry years. These are defined respectively according to the percentage distribution of flow values when these are arranged in order of frequency as shown in Figure Ia (bottom scale). Such a classification may be used to express indices such as are shown on Figure II in terms of their frequency if the frequency distribution of modular coefficients is known.

14. Other methods of analyzing the probability of levels of year-to-year inter-basin diversity are available. The question can, for example, be studied by calculating coefficients of correlation between rank-order values of flow frequency in different basins and one chosen as standard. This is illustrated in simple form in Table 1, where Spearman rank-order correlation coefficients are employed. Such coefficients may also be mapped by isopleths. Another more sophisticated

method of expressing and mapping inter-regional diversity is also available and is in course of being worked out for a study in progress (under the work programme of the Group of Experts referred to above) covering basic seasonal characteristics of the hydro-electric potential of Europe's water resources and their diversity from year to year.

(d) Energy potential of hydraulic resources

15. The physical potential of the stream flow in different river basins of a region should also be established and mapped, at least in its main outlines, to throw light on the sources of hydro-electric power. A fixed upper limit to the usable potentiality of a basin is that given by the gross surface hydro potential. This has been defined by the Group of Experts referred to above as follows. Gross surface potential in 10^6 kWh/year for a given catchment area is given by the formula:

$$\frac{FH}{367}$$

where F = mean annual runoff originating in the catchment in $10^6 m^3$; and H = mean elevation (in m above mean sea level).

16. It is evident that this mean annual surface potential (and also the mean seasonal potentials if desired) can be determined from the data worked out above for the largest possible number of unit catchment areas. To map the geographical distribution it is necessary to plot each separate value (expressed in kWh/m^2) at the centre of the unit of area to which it applies and then to interpolate isopleths at a convenient interval (Figure III).

17. Because it remains constant (apart from errors in the runoff assessment) this gross surface potential defines a fixed upper limit to hydro-electric resources against which changes in the conception of exploitable possibilities may be compared. The aggregate exploitable potential in kWh, after taking into account losses of head, flow, incomplete utilization of generating capacity and other limiting factors, commonly amounts to an overall average of around 20 per cent of the gross value in various European countries under present conditions, though in suitable cases the portion found economically usable may be much higher.

18. It is unnecessary to discuss here in detail the refinements of this type of survey. The European distribution of gross annual surface potential has been worked out and mapped under the work programme of the Group of Experts for Study of Hydro-electric Resources in Europe and the results, plus a detailed account of the methodology, will be found in reference (6). References (1) and (3) also describe the work entailed in applying this concept to determine rapidly the order of magnitude of hydro resources in regions where information is scanty.

19. Specifications for carrying out an equally comprehensive but more detailed evaluation to determine the distribution of hydro-electric potential along each individual watercourse have also been worked out. These give a gross or net river potential. The latter approximates to the upper limit that is technically (but not necessarily economically) exploitable (7). It assumes, however, the existence of suitable stream-flow data and is therefore likely to represent a later stage in the evaluation, or to be confined to certain basins only. The characteristics of various successive types of hydro resource evaluation will not be dealt with here in detail since they may be studied in reference (6) already referred to.

20. Methods for expressing and comparing the economic feasibility of hydro-electric projects under particular national conditions have been worked out (see for example,

references 8 and 9). In any case it is normally useful to compare information about existing hydro plants and any projected schemes with the results of theoretical evaluations of the type referred to above. The foregoing analyses provide in principle (and in addition to rapid assessments on the ground) a good deal of information for considering water storage possibilities and requirements and may well offer indications as to where any feasible multi-purpose schemes might be envisaged.

21. Before turning to the economic inventory proper it should be stressed (with respect to frequency and diversity for example) that only the barest outline of a methodology has been given above. Some of the methods outlined may also be inapplicable at the outset. For lack of space many problems and possibilities have been neglected. Various aspects of the actual or planned development of hydro power in European countries, and rates of harnessing of the unexploitable resources, may for example be studied in reference(10).

III. The Economic Inventory

22. The methods outlined above are those which have been applied in concrete cases to ascertain, rapidly and throughout entire countries, the approximate total distribution of the available water resources, and the water power potential associated with them, where no such comprehensive picture has existed previously and where normal data have been insufficient for such a purpose. Assuming now that the average total supply emerging as surface runoff is very approximately known (ground water stored as a reserve has not been specifically discussed) it is time to consider the inventory of requirements, again from the point of view of basic methods of approach.

23. The analysis of water needs is a complex matter and could obviously occupy a lengthy report in itself. For the present purpose needs may be taken as those, mainly for consumptive use, for domestic, commercial, small industrial and service requirements in urban and rural areas; those required for use by industry, including power supply; and those required for irrigation and agriculture generally and for canalised water transport.

24. All these uses involve losses or deductions. Use by industry, which is mainly for cooling and processing, comprises a large but very variable percentage of internal recycling - amounting to some 40 per cent or more overall - and a certain amount of consumptive use. Recycling also exists in the sense that some supplies may be used again and again for different purposes along a section of watercourse. The amounts of water actually in circulation in industrial plants should tend to vary with the volume of production while the development of recycling appears to be very variable from case to case and area to area (its development so far appears often to be roughly in proportion to the cost and availability of supplies) and is thus difficult to evaluate. Effective consumption by industries may be taken as the difference between the quantities deducted in a given period (from surface or underground sources) less the amounts rejected.

25. Where all main water-using industries are represented industrial census figures seem to show that around 80 per cent of total industrial use is accounted for by a few predominant groups - basic metals, including the steel industry; chemicals; pulp and paper; and coal and petroleum (11). Use of cooling water by power plants is in a different category but on the basis of water in circulation it accounts for something like double the amount in use by all other industries in various industrialized countries where thermal power plants predominate in the electricity supply. Of the remaining needs for water those for irrigation include losses

which, in moderate latitudes, may vary between about 20 and 50 per cent depending on the use made of high-efficiency techniques and the proportion of semi-arid land. Requirements to maintain canalised navigation allow for losses - i.e. due to the difference between evaporation and precipitation; to seepage into the water table; and to losses at locks which are in fact transferred to adjoining sectors.

26. The question of the yearly regime of water requirements and their various peaks is of importance, not only in hydro power plants where the question of regulation is paramount, but also in virtue of the fact that requirements and losses in various sectors may be at a maximum at low-water periods (12).

(a) Appraisal of total requirements at a given time

27. Expressed in m^3/year per inhabitant, gross consumption of water of drinking quality for domestic, municipal and related uses commonly varies considerable in different aras of a country in accordance with size of communities and density of population. While it may be well under 50 m^3 in rural areas consumption may amount to three times that figure in highly developed European cities of around 500,000 inhabitants. The requirement of the total domestic sector may be broadly evaluated on that basis from sample inquiries in different areas of supply. It is, however, necessary to take into account the percentage of population served by public supply. Losses are commonly taken to amount to something of the order of 20-25 per cent of gross requirements.

28. Total industrial needs must be roughly evaluated from sample inquiries or from special questions included in an industrial census, plus an application of data on specific needs per unit of product. Ideally, withdrawals in a given period less discharges would give effective consumption and it is desirable to have estimates for quantities in circulation. In fact, any assessment must probably be highly approximate. Data which exist for various industrialized countries show very wide variations in actual requirements per unit of product and in use of recycling (11).

29. Water for irrigation and agriculture generally serves in temperate latitudes to reduce irregularities in production as well as to extend the land under cultivation. Requirements may be estimated broadly in terms of irrigated area, rates of evapo-transpiration and overall efficiency of water use.

30. Water needs to maintain the levels of navigable canals and other artificial water storage installations can be evaluated from a knowledge of their length and average specifications, plus estimates of annual losses per unit of length for seepage, evaporation, etc. The importance of this type of requirement in the total must vary widely from case to case.

(b) Evaluation of future needs

31. Methods of projecting the future development in water requirements resemble in various respects those used in estimating consumption needs for other public utilities and for energy needs in general. Some of the principles set out in the companion report on evaluation of foreseeable energy requirements (13) thus prove useful in the present field also.

32. The needs for water of drinking quality by the total "public supply" sector referred to above (domestic and allied category of consumers) can be forecast for the medium term by applying to the projected population, increases expected in specific consumption less any reduction in losses. Urban and rural populations may be treated separately so far as possible because of the need to allow for

extensions of supply to new consumers. Study of levels of use per inhabitant in more industrialized countries may give indications of the likely trend in per capita use for this purpose.

33. Most of the industrial requirements are not for consumptive use but rather act to modify and reduce the quality of the water discharged from the installation. Moreover, some of the withdrawals from underground sources are rejected into surface supplies. In some sectors, as for thermal power plants, specific requirements may be reduced somewhat by technical progress while in others they may rise steeply. In general, total industrial needs may be projected on the basis of the expected trend in industrial production. Development of recycling appears to depend somewhat on water cost and availability and this aspect must therefore be treated with reference to local conditions. Trends in other more industrialized countries may provide useful indicators of the long-term development in industrial needs. In general, estimates for such countries tend to assume degressive rates of growth for this particular type of water use.

34. The other requirements, mainly for irrigation and possibly for maintenance of artificial waterways, may be estimated in the one case by reference to plans for extention of irrigated areas; and in the other by reference to projects for extending canal systems, any changes in the factors mentioned earlier being taken into account in the process.

35. Forecasts of the evolution of total requirements for different countries differ rather widely in their growth rates and in levels of use per inhabitant. An example of a forecast of total withdrawal requirements for France up to 1970 is shown in Table 2. This may be taken as an example of a consolidated assessment of all main requirements other than those of hydro-electric plants, which (apart from evaporation from reservoirs) merely utilize available supplies without changing their quality or quantity to any great extent.

36. In the main, the methods available for projecting hydraulic needs are seen to be those included in the third and fourth of the types of method discussed in the companion report on energy forecasting methodology, plus some possible use of the second type where industry is concerned. It is instructive to compare the problems and methods confronting the projection of needs in these two fields.

IV. Comparison of Resources and Needs

37. From various procedures of the type outlined above it may be possible, though by no means easy, to arrive at some rough preliminary conspectus of water resources and main needs on a comprehensive basis long before sufficient stream flow and other data have been accumulated to make a full analysis possible. When the apparent total requirements for water are compared with the available surface runoff for an entire country, plus any probable ground water reserves, it may appear that there remains a wide margin of surplus between the two. The essential problems which emerge may well be posed rather differently: How far may supplies suffice in particular areas of low availability and a possible high peak demand? To what extent can the different requirements - for flow regulation, power supply and irrigation, for example - be harmonized in an economic way? Rapid preliminary but comprehensive surveys of water resources are capable of throwing light on such questions. They have in practice proved useful also in aiding the setting-up of a comprehensive network for stream flow recording at strategic sites and for planning basic research and the regular assembly of relevant data.

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12. Darlot, Darves-Bornoz & Perrin-Pelletier: Les besoins en eau d'une nation industrialisée; Annales des Mines, Paris (January 1962).

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Additional references not referred to in the text:

14. Water for Industrial Use. (doc. E/3058). United Nations, New York (1958).

15. Half-Yearly Bulletin on Conditions of Hydraulicity in Europe. (Vols. 1 - 3, 1959 - 1962), United Nations, Geneva.

16. T. Berglund & S.O. Larsson: Gross Mean Hydro-electric Potential in Sweden. Swedish State Power Board, Stockholm (1959). This study employs methods outlined in the paragraphs 15-18 of the present report.

17. Austrian Hydro-Power Register: Gross River Potential. Ministry of Trade and Reconstruction, Vienna (1960). This survey provides an example of a national inventory of river potential on the lines discussed in paragraph 19.

Table 1

Rank-order correlation coefficients, (for both winter and summer half-years over a common 30-year period) in respect of the Rhine at Bâle and certain other selected river basins in Europe

River, gauging point and approximate distance from Bâle	Coefficient of rank-order correlation with Rhine at Bâle (1)	
	Summer half-year	Winter half-year
1	2	3
A. Within 500 km		
Danube (Hofkirchen)	0.821	0.841
Rhône (Porte du Scex)	0.537	0.801
Meuse (Visé)	0.742	0.710
Durance (Mirabeau)	0.548	0.338
B. 500 - 1000 km		
Garonne (Mas d'Agenais)	0.537	0.443
Sava (Sr. Mitrovica)	0.340	0.632
Tevere (Roma)	0.807	0.509
C. 1000 - 1500 km		
Duero (Villachica)	0.337	0.522
Drina (Zvornik)	0.351	0.587
Mondego (Coimbra)	0.443	0.453
D. Over 1500 km		
Dnieper (Dnepropetrovsk)	0.317	-0.034
Vuoksi (Imatra)	0.232	-0.084
Kemi (PetKjÄskoski)	0.009	-0.233
IndalsÄlven (Östersund)	-0.211	-0.128

(a) Values express Spearman's coefficient of rank-order correlation over a standard 30-year period, i.e. from the formula:

$$1 - \frac{6\sum(d^2)}{N(N^2 - 1)}$$

where d = differences between corresponding rank-order values and N = the number of values in a series. For a standard period this expression can be reduced to a very simple form.

Table 2

Projected development of requirements for water (1955 - 1970)[a] in an industrialized country in temperate latitudes (France)

Categories of Use	1955 (population 43 million)			1970 (population estimate 49.1 million)			
	Actual needs			Projected needs			
	10^9 m^3/year	m^3/inhabitant per year	As percentage of total	10^9 m^3/year	m^3/inhabitant per year	Index for col. 6 (col.3 = 100)	As percentage of total
1	2	3	4	5	6	7	8
Domestic sector[b]	1.9	75	9.5	4.0	80	106	12
Industry (in circulation)	(10.4)	(240)	-	(23.0)[c]	(470)	-	-
Industry (withdrawals)	6.5	150	34.0	14.0[d]	290	193	41
Irrigation and agriculture	10.0	230	50.0	14.5	400	174	43
Canal navigation	1.3	30	6.5	1.5	30	100	4
Total withdrawals	19.7	-	100.0	34.0	-	152	100

(a) Based on material in reference (12).

(b) Includes municipal needs etc. (drinking water quality).

(c) Of which 16.0 for electric power plants (3 for nuclear plants) with 31 per cent recycling and 4.5 for the steel industry (65 per cent recycling).

(d) Of which 11.0 for electric power plants and 1.6 for the steel industry.

Figure I a

EXAMPLE OF DURATION CURVE
(SUMMER AND WINTER PERIODS ONLY)
TO STANDARD ARITHMETIC SCALE

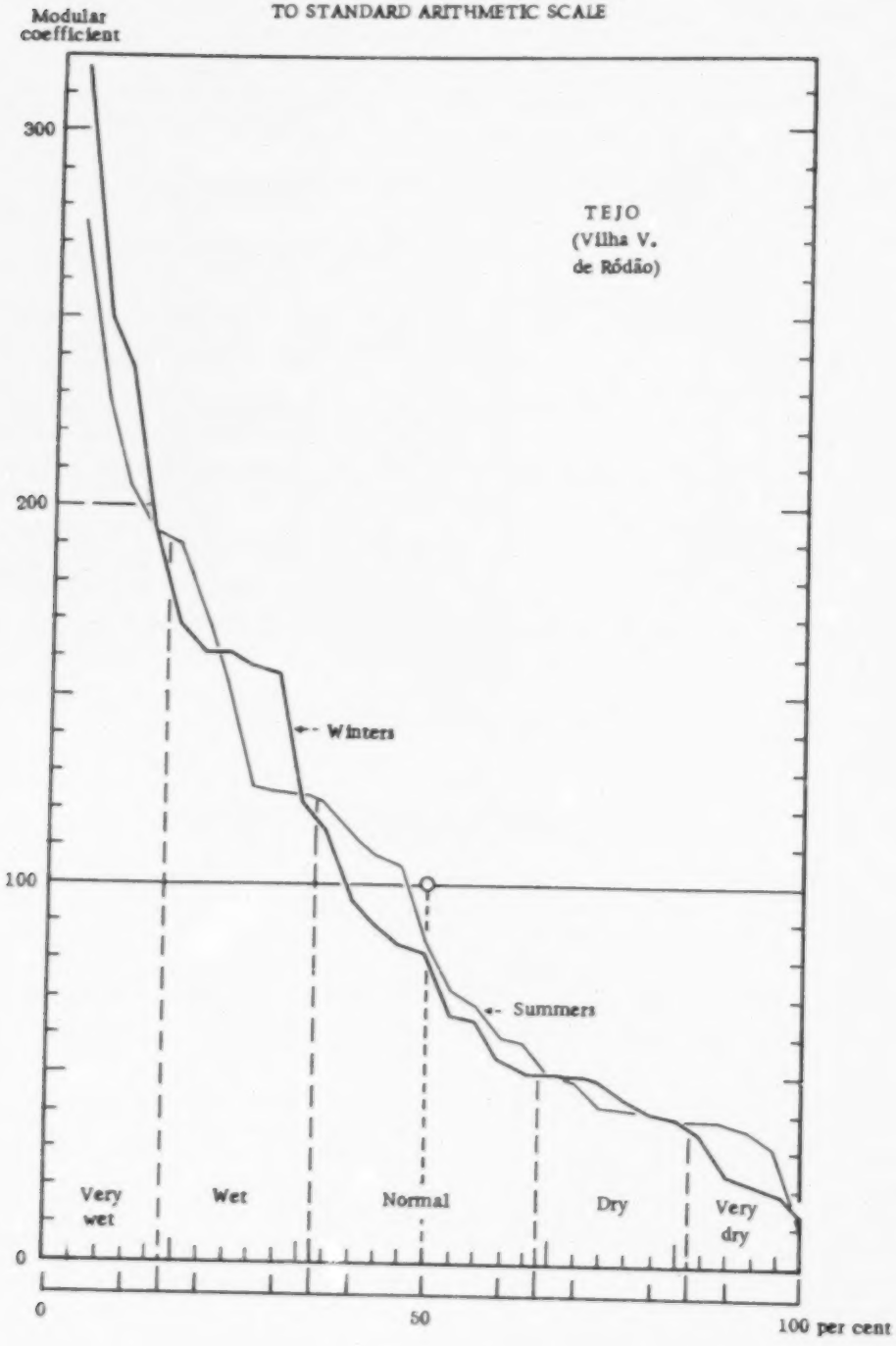


Figure Ib

FREQUENCY / PROBABILITY DISTRIBUTION OF SUMMER AND WINTER HALF-YEARS
FOR SELECTED RIVER BASINS OVER 30-YEAR PERIOD
(logarithmic and probability scales)

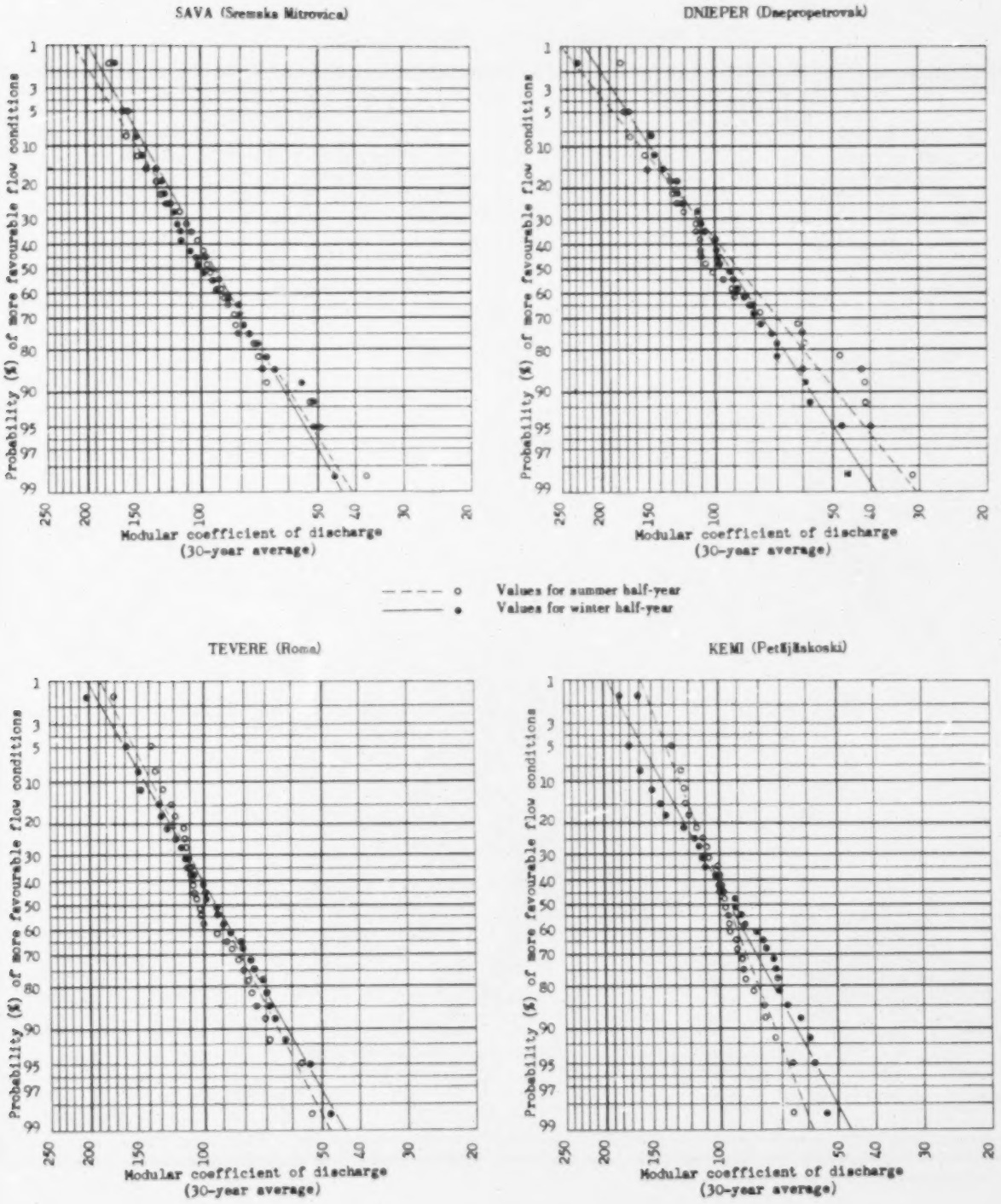
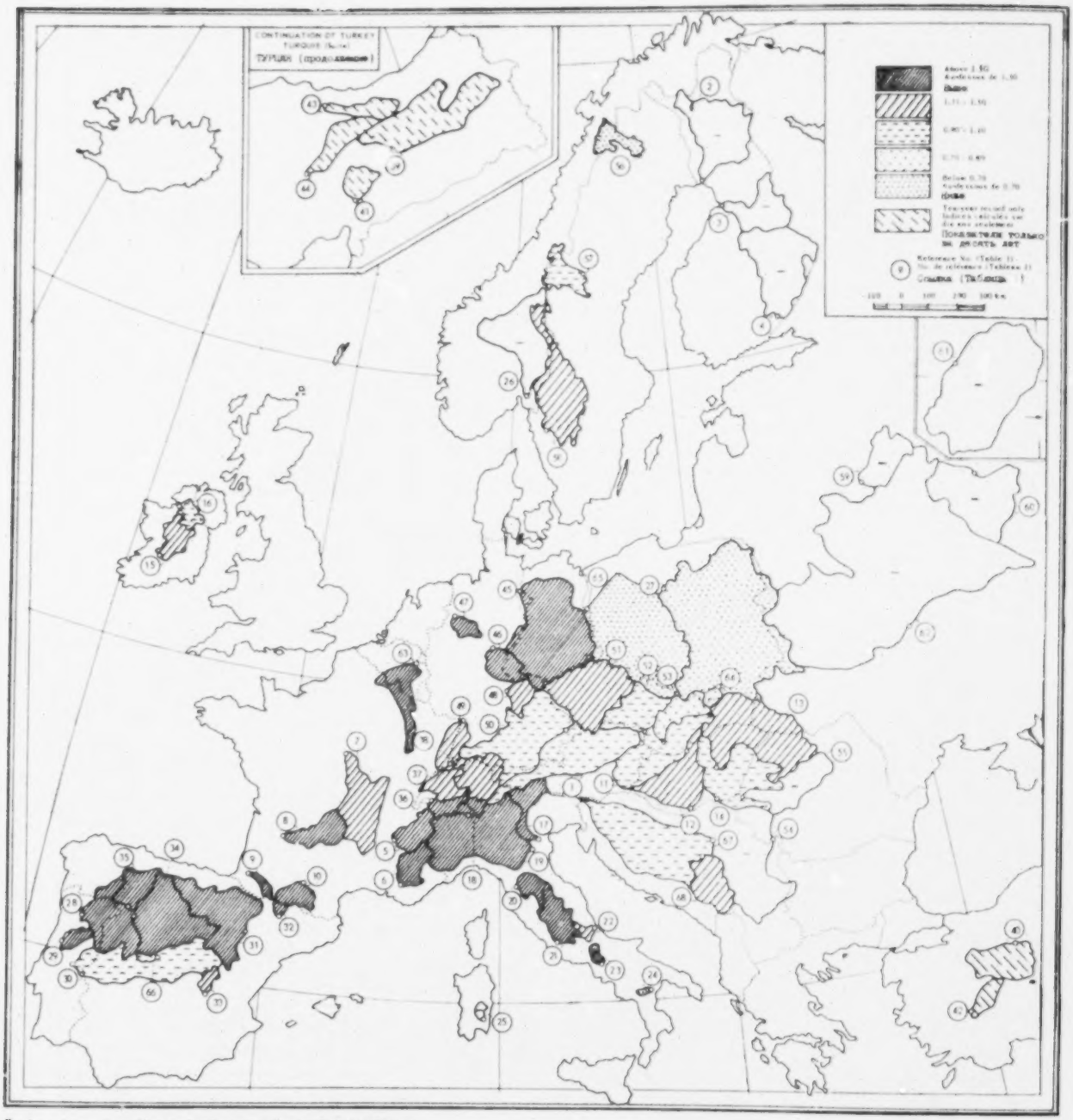


Fig. II - Fluctuations in hydraulic conditions in Europe, relative to the long-term average, over the period October 1960 to September 1961

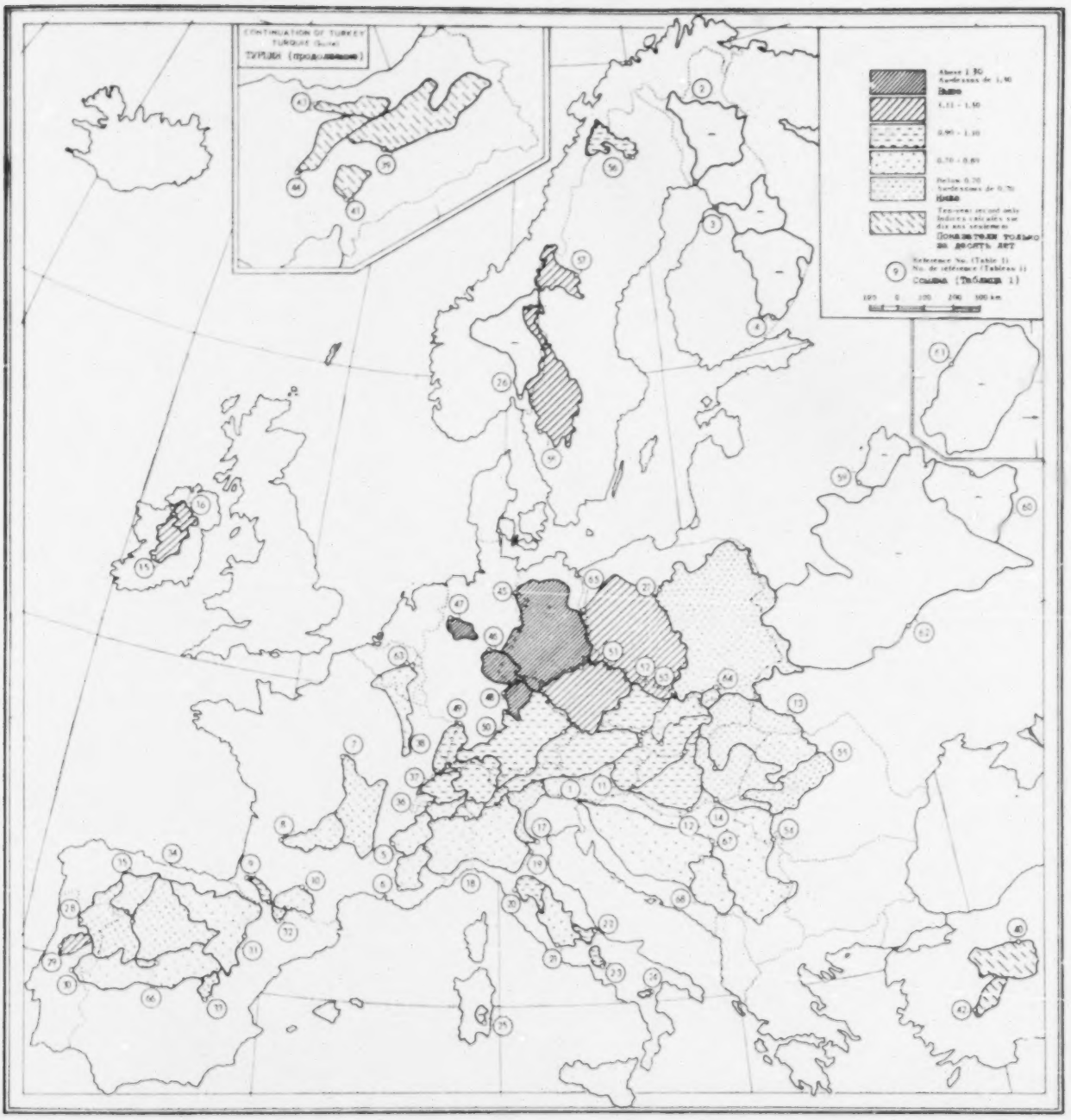
OCTOBER 1960 - MARCH 1961



Boundaries shown on this map do not imply endorsement or acceptance by the United Nations

Fig. II - Fluctuations in hydraulic conditions in Europe, relative to the long-term average, over the period October 1960 to September 1961

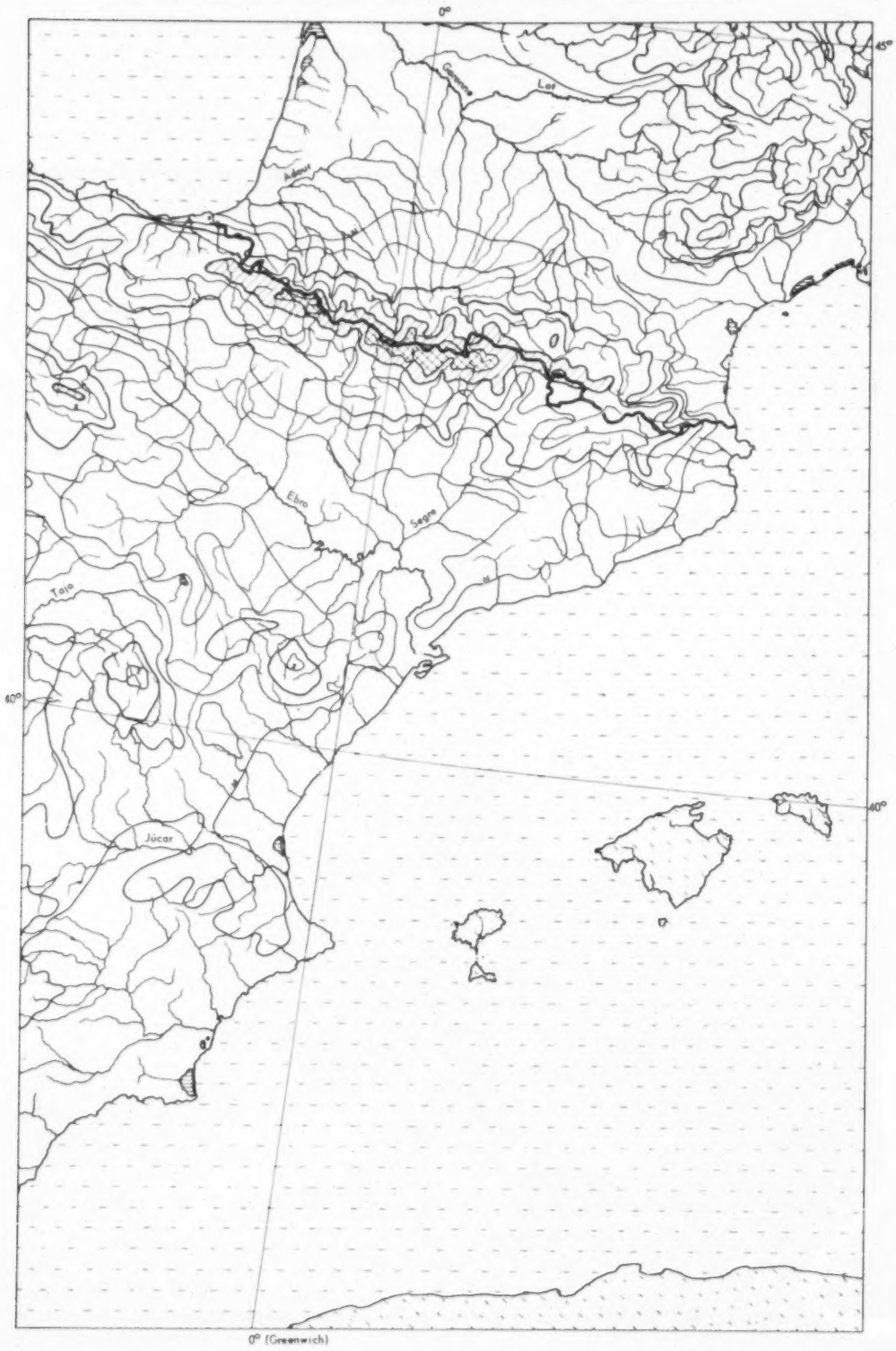
APRIL - SEPTEMBER 1961



Prepared by United Nations Economic Commission for Europe

FIGURE III

EXAMPLE OF MAP SHOWING GROSS SURFACE HYDRO-ELECTRIC POTENTIAL BY ISOPLETHS



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